Appendix J
Live Fire Vulnerability/Lethality Issue: System Evaluation Considerations

J–1. Overview of live fire

a. Title 10, United States Code, mandates that major weapon system and munitions programs, as well as product improvements to those programs that are likely to significantly affect the vulnerability or lethality of those programs (respectively) undergo a realistic Live Fire Test and Evaluation (LFT&E) program. This section provides guidelines for test design and evaluation planning for LFT&E programs. It also presents the basis for determining whether a LFT&E program is required for a given system, and describes the key steps in developing an adequate and acceptable LFT&E strategy, including the role of modeling and simulation in the LFT&E process. Specific guidance on the planning, execution, reporting of live fire tests is provided in chapter 6 and appendix S.

b. LFT&E is necessary because it is the law; but, more importantly, because it is cost effective and smart testing. A realistic LFT&E building block program represents the best alternative to "actual" combat in assessing the system's performance. However, with the lack of actual combat data must come a disciplined and realistic approach to assessing the vulnerability and lethality of our weapon systems. The Full-Up System Level (FUSL) LFT component of the LFT&E program provides the means for assessing the synergistic effects of system component integration and of selected damage mechanisms. A well-planned and well-structured LFT&E program reduces the potential for "surprises" before that system's arrival on the battlefield.

c. An active, well-planned, well-managed, and well-executed LFT&E program is essential to understanding system vulnerability/lethality (V/L) and will be an essential element of the information supporting decisions regarding the acquisition of materiel as well as the development of doctrine, plans, and JMEMs for its proper operational employment. When properly structured and scheduled, the LFT&E program will enable design changes resulting from that testing and analysis to be incorporated into the system at the earliest possible date and reduce the need for expensive retrofit programs.

d. Figure J–1 illustrates the basic elements of the overall LFT&E process from initial strategy definition to the writing of the final test and evaluation reports. While the details of each element of this overall process must be decided on a case-by-case basis, this guidance presents the general approaches and lessons learned from initial LFT&E programs that have proven successful and that should prove beneficial to those individuals involved in future LFT&E programs.

J–2. Objective of LFT&E

a. The LFT&E program supports a timely and thorough assessment of the vulnerability/lethality of a system as it progresses through its development and subsequent production phases. It should demonstrate the ability of the weapon system or munition to provide battle resilient survivability or lethality and provide insights into the principal damage mechanisms and failure modes occurring as a result of the munition/target interaction and into techniques for reducing personnel casualties or enhancing system survivability/lethality. These insights will mature during the course of the system's LFT&E program. Data will emerge that will identify specific failure modes and damage mechanisms. The data can be used to support cost effectiveness tradeoffs to predict the optimal "mix" of vulnerability reduction/lethality enhancement measures early (prior to MS B) in the acquisition cycle (see the Defense Acquisition Guidebook).

b. The primary emphasis of LFT&E is on realistic combat conditions testing as a source of personnel casualty, vulnerability, and lethality information to ensure potential design flaws are identified and corrected before full-rate production. The LFT&E program should assess a system's vulnerability/lethality performance relative to the expected spectrum of battlefield threats; it is not constrained to addressing specific design performance goals or threats. However, LFT&E by itself is not a basis for the decision to transition to full-rate production; many other factors must be considered in arriving at this decision. Additionally, LFT&E will provide insights into how to enhance the survivability and/or lethality of similar or future systems and provide a mechanism for gaining insights into the adequacy of vulnerability/lethality assessment techniques and supporting databases. LFT&E should exploit opportunities to assess the capabilities of battle damage assessment and repair to further system survivability.

J–3. Background of LFT&E

The genesis of LFT began in the early 1980s as the outgrowth of perceived needs by two separate groups. First, the vulnerability/lethality assessment community was concerned that the technological viability of their assessment techniques was becoming increasingly tenuous. They were relying more and more on questionable extrapolation of existing databases (rapid advances in technology over the past two decades had simply made many of these databases outdated and inapplicable). Due to the increasing complexity of foreign and domestic weapon systems and of the munition/target interaction, assessment techniques demand a strong tie to empirical databases including those based on firings against full-up targets. Staff personnel within Congress, the Office of the Secretary of Defense (OSD), and Headquarters, Department of the Army (HQDA) were concerned that testing programs were ignoring the realities of war and were not providing a realistic and rigorous assessment of the likely performance of these systems in combat. They felt that program decisions were too dependent on modeling and component testing and that full-up LFT was needed to judge how well these systems—and the crew who operated them—would survive on the modern battlefield.

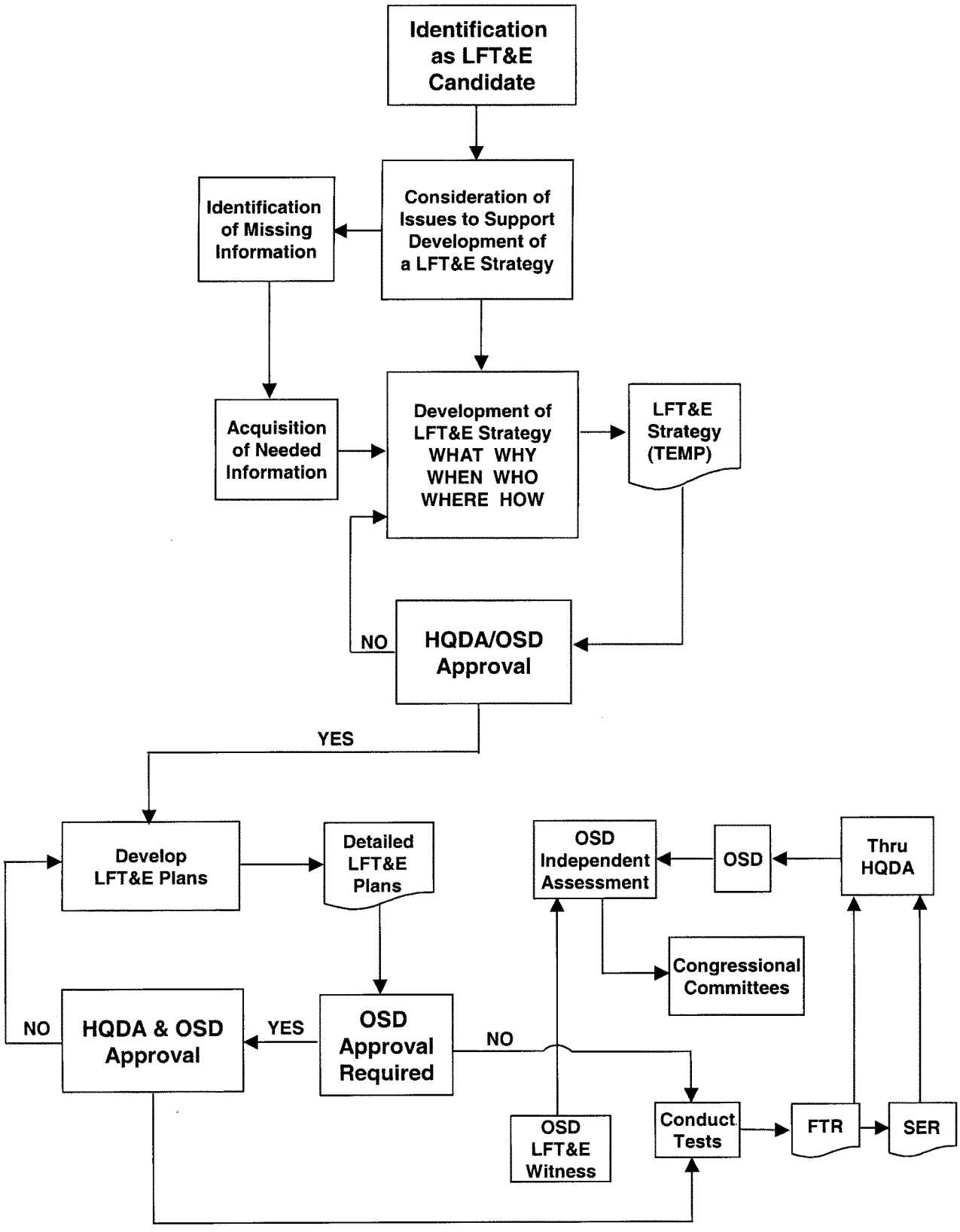

Figure J–1. Overview of the LFT&E process

a. The need for full-up testing led to the establishment of the Joint Live Fire (JLF) Program in March 1984. The JLF Program was and continues to be sponsored by OSD as a joint test initiative. The JLF Program is chartered to assess the vulnerabilities and lethalities of fielded conventional U.S. ground systems and aircraft. Army systems initially included in the JLF Program were the Bradley Fighting Vehicle System, the Abrams Tank, and the M113 Family of Vehicles. Because of differences in the philosophic approach to LFT between the Army and OSD (the building-block approach versus large scale full-up testing) and the Army's desire to accelerate the testing of these systems, the Army subsequently requested and received permission from OSD to withdraw the Bradley, Abrams, and M113 systems from the JLF Program. The Army agreed to fund the cost of the LFT programs for these systems and to provide OSD open access to test planning, test conduct, and test results. This series of LFTs was known as Army LFT and was completed in 1988.

b. The need for LFT led Congress to mandate such testing for major weapon system and munition programs through a series of amendments to Title 10, United States Code, in the FY86 through FY94 Department of Defense (DOD) Authorization Acts and in the Federal Acquisition Streamlining Act of 1994. Table J–1 presents a comparison of the primary features and differences among the JLF, the Army Live Fire, and the congressionally legislated LFT&E programs. The remainder of this pamphlet discusses the requirements and strategies applicable only to congressionally legislated LFT&E programs.

Table J–1
Comparison of joint live fire, Army live fire, and LFT&E programs required by Title 10 of United States Code (USC)

Joint Live Fire	Army Live Fire	Title 10, USC
Chartered FY84	Legislated/Chartered	Legislated FY86–FY94
Multi-Service	Army only	Individual/Multi-Service
OSD funded	Army funded	Service funded
Fielded systems	Bradley, Abrams, M113 Family	Developmental systems/PIPs
Vulnerability/lethality	Vulnerability	Vulnerability/lethality
Armor/anti-armor, aircraft	Armor	Air, land, sea systems
Test event oriented	Test event oriented	Milestone oriented
OSD oversight	OSD oversight	OSD oversight

J–4. LFT&E legislation

The FY86 and FY87 DOD Authorization Acts amended Section 139 of Title 10, United States Code, to require LFT&E before proceeding beyond low-rate initial production (LRIP). Specifically, the FY86 legislation requires side-by-side vulnerability LFT&E if a wheeled or tracked armored vehicle is to replace an existing vehicle; the FY87 legislation requires LFT&E for all covered systems and major munition and missile programs. The FY88–89 DOD Authorization Act amended Title 10 to include a LFT&E requirement for product improvements to major systems (that is, system changes (modifications or upgrades)). The FY90–91 Act requires DOD to report results of LFT before a system enters full-rate production and also acknowledges that procurement funds can be reprogrammed to support LFT&E programs (such funding will not exceed one-third of one percent of the total program cost). The FY94 DOD Authorization Act eliminates redundant sections of Section 139 of Title 10 including the requirement to conduct comparison testing with existing vehicles being replaced. The Federal Acquisition Streamlining Act of 1994 transfers oversight of Live Fire testing from the Office of the Deputy Director, Defense Research and Engineering (Test and Evaluation) to the Director of Operational Test and Evaluation, OSD.

a. To summarize, the current legislation requires that the Secretary of Defense provide that—

(1) A covered system not proceed beyond LRIP until realistic survivability testing is completed.

(2) A major munition or missile program not proceed beyond LRIP until realistic lethality testing is completed.

(3) A covered product improvement program not proceed beyond LRIP until realistic survivability/lethality testing is completed.

b. The legislation states that the costs of all survivability/lethality testing will be paid from funds available for the system being tested. The legislation also allows the Secretary of Defense to waive the requirement for survivability/lethality testing in time of war or if the Secretary certifies to Congress, before the system enters engineering and manufacturing development, that LFT of the system would be unreasonably expensive and impractical. Per Department of Defense Instruction (DODI) 5000.2, all acquisition programs, excluding highly classified programs, will be placed into one of three categories: Acquisition Category (ACAT) I, ACAT II, or ACAT III. ACAT I and ACAT II programs are major defense acquisition programs and major programs, respectively, and, if they are covered systems or a

munition/missile system, will have a LFT&E requirement. Non-major (ACAT III) munition/missile programs may have a LFT&E requirement if they meet the one million round production requirement.

J–5. Requirement for LFT&E

Figure J–2 provides a flow chart to assist in determining a system's LFT&E requirement. This flow chart addresses both new systems and system changes (modifications, upgrades, or follow-on blocks) to existing systems. Specific situations (for example, the LFT&E requirements for changes to existing systems that have undergone LFT&E) must be addressed on a case-by-case basis. If a system meets the LFT&E dollar or quantity criteria or if a system change provides a significant vulnerability/lethality effect, the system has a LFT&E requirement. The degree of LFT&E needs to be addressed in a comprehensive LFT&E strategy, incorporated into the appropriate documentation, and provided to the Army leadership for guidance and approval. Per DODI 5000.2, a system's proposed acquisition strategy and evaluation strategy developed during Pre-Systems Acquisition (Concept and Technology Development) include LFT&E testing requirements in addition to DT, OT, and System Evaluation. Army policy requires a system's LFT&E requirement be identified to the U.S. Army Test and Evaluation Management Agency (TEMA) and a mature LFT&E strategy and resource requirements be included in the Milestone B Test and Evaluation Master Plan (TEMP) (see the Defense Acquisition Guidebook).

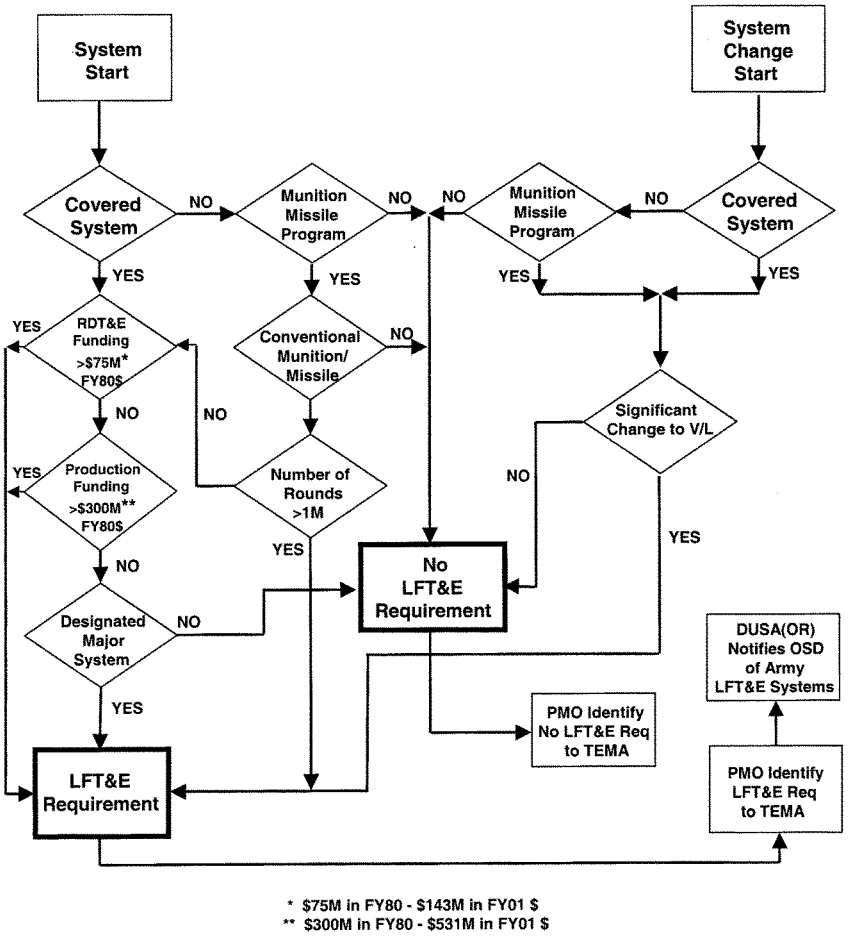

Figure J–2. LFT&E requirements flow chart

J–6. Keys to success

The LFT&E program has and will continue to be one of the most complex and high-visibility T&E phases during weapon system development. It requires proper planning, resourcing, testing, evaluation, and coordination to ensure that critical vulnerability/lethality issues are effectively and adequately addressed and that the congressional mandate is satisfied. Based on the experience gained during previous Army LFT Programs, a number of "keys to success" have been identified that should be useful for future LFT&E programs. These keys include—

a. Integration into the test and evaluation (T&E) process. The requirements of LFT&E are comparable to those of any test and evaluation (T&E) program. The T&E WIPT is supported by the LFT&E WIPT, a subgroup formed to coordinate LFT&E planning activities. The LFT&E WIPT is chaired by the system evaluator

b. Early planning. The resource demands, plus the review and approval process, for LFT&E make early planning absolutely essential. Early identification of the critical vulnerability and/or lethality issues, the LFT&E strategy, the test resource requirements, test limitations, and inclusion in the TEMP are necessary to provide:

(1) HQDA/OSD with an understanding of the basic strategy and the adequacy of planned testing, evaluation, and resources.

(2) The PM with an understanding of the resources required, including the system hardware and threat or threat surrogate requirements, many of which require long lead times to procure or develop.

c. Building-block approach. The key to understanding a given munition/target interaction is an understanding of the underlying phenomenology. These insights can often be gained and many critical issues addressed through component and/or sub-system level T&E. Thus, the most cost effective and efficient approach to LFT is a building-block approach. Using such an approach, a development program would progress from early component level T&E, to sub-system/system level T&E, and culminate in a limited series of full up system level (FUSL) Live Fire Tests. These firings address personnel casualty, the synergisms of various damage mechanisms, and critical system vulnerability/lethality issues that can only be answered through FUSL LFT&E. The building-block approach provides the earliest possible understanding of the munition/target interaction phenomena during the development process and enables required fixes to identified problems be incorporated at the earliest possible date. This approach also affords the MATDEV with a step-wise approach to acquire test information in the system design process. Evaluating the system's design for incorporating vulnerability reduction features early allows the MATDEV to evaluate alternatives to providing combat survivable systems to the user.

d. LFT&E WIPT. The complexity of LFT&E programs requires that a broad range of technical, programmatic, and management expertise be brought together for the planning, execution, and reporting of that program. A matrix team approach has been found to be the most effective and efficient approach in previous LFT&E efforts for bringing this diverse set of expertise and activities together and ensuring a coordinated and credible LFT&E program. Thus, successful execution of a LFT&E program demands the early recognition of the need for, the solicitation of, the support of, and the continuous involvement of all necessary activities. Principal team members typically include the system developer, combat developer, system evaluators, vulnerability/lethality analysts, testers, medical community, intelligence community, and system contractor (as required). OSD (DOT&E) and DUSA(OR) are invited to provide members since these offices have oversight responsibilities. Generally, this matrix team will remain in existence throughout the LFT&E program and should be organized as a separate working group under the T&E WIPT. Membership may be expanded or modified to include user representatives and others as required (for example, for vulnerability programs involving ground vehicles and air platforms, the BDAR Executive Agent may be included) and as the program evolves.

e. LFT&E discipline. Because of the high visibility of LFT&E programs and HQDA and DOT&E approval of selected LFT&E documents, the LFT&E process must assure strict adherence to HQDA and DOT&E approved documents or obtain approval of changes by HQDA and DOT&E. Test discipline is discussed in greater detail in chapter 6.

J–7. Roadmap to live testing and evaluation

The development and subsequent approval of the LFT&E strategy is a critical step in the overall LFT&E process. The LFT&E strategy is a documented concept that describes who, what, why, when, where, and how the LFT&E requirements for a given system will be satisfied. Just as a system's acquisition strategy outlines the top level approach for the overall system acquisition, the LFT&E strategy provides the top level description of the LFT&E portion of the system's test and evaluation strategy and is an integral part of the TEMP. Once approved, the LFT&E strategy provides the basic roadmap for what vulnerability/lethality testing and evaluation has to be conducted before transitioning to full-rate production. While the details of the LFT&E strategy will vary from system-to-system, this chapter attempts to provide the general details necessary for the development of an adequate and credible LFT&E strategy. Development of the LFT&E strategy requires an understanding of both the system's acquisition strategy and the overall T&E process.

J–8. Events schedule

Figure J–3 depicts where the elements of the required vulnerability/lethality assessment and the LFT&E program fall within the materiel acquisition process as outlined in DODI 5000.2. Table J–2 presents an outline schedule of LFT&E events that, if followed, will result in a timely and effectively executed LFT&E program. The schedule for the EDP, Final TR, and SER are mandated requirements.

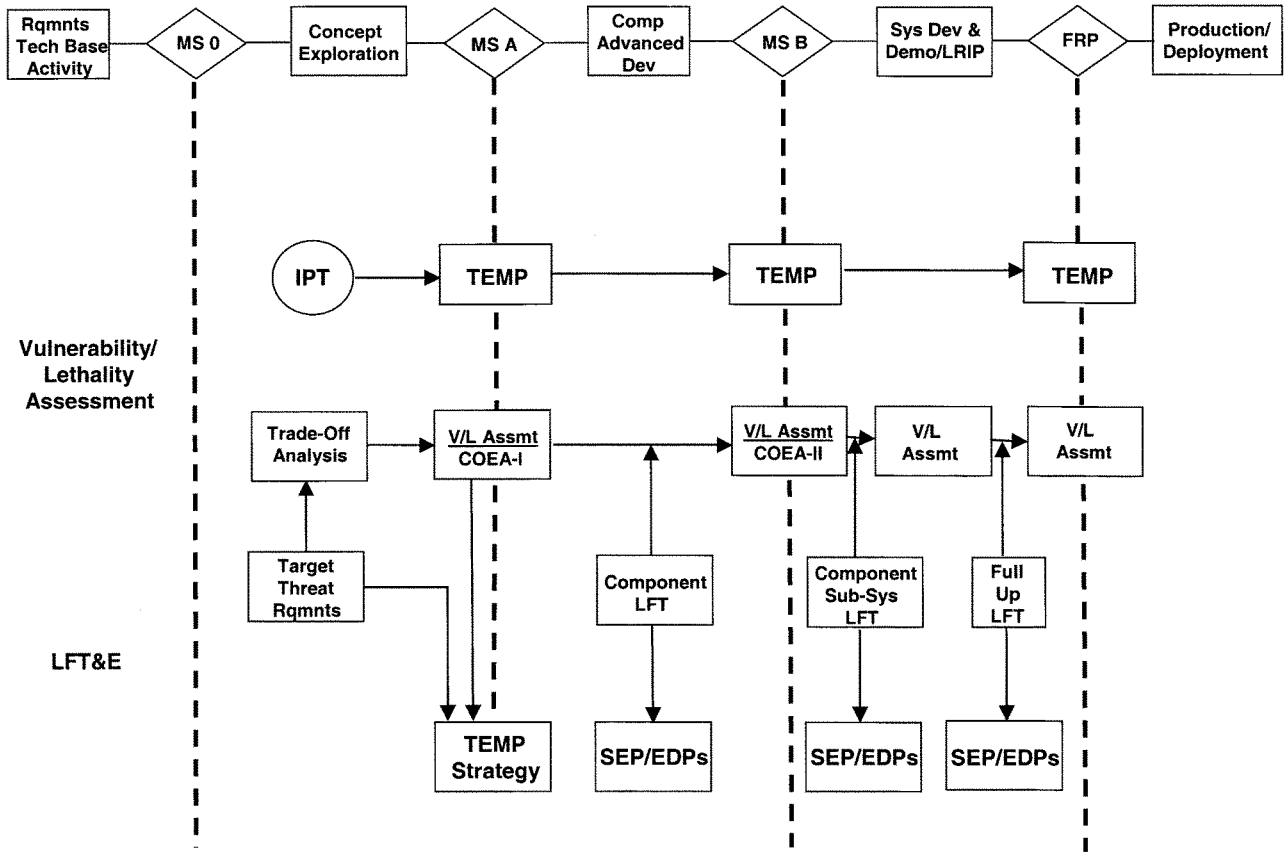

Figure J–3. Conceptual LFT&E approach to systems acquisition process

J–9. Live fire in the T&E process

Live Fire tests may consist of component, subsystem, and/or system level tests in addition to the FUSL tests of system vulnerability and lethality. The FUSL Live Fire Testing is the testing that fully satisfies the statutory requirement for "realistic survivability testing" or "realistic lethality testing" (as defined in Title 10 of the USC) and is required, with OSD oversight, before a program may enter full-rate production. The LFT&E program examines the full spectrum of battlefield threats, to include overmatching threats, as opposed to the design level threats. The LFT&E program includes all vulnerability/lethality T&E phases and associated modeling and analysis efforts that support the Live Fire evaluation. Resource and schedule constraints and the stochastic nature of the FUSL LFTs generally limit the scope of these tests to a demonstration of system vulnerability and lethality.

Table J–2
Live fire test and evaluation event

Schedule	Live fire test and evaluation event	Lead	Lead for resources
Pre-MS A	Working Group Formation	ATEC (AEC)	N/A
MS A	Initial TEMP Input	ATEC (AEC)	PM
MS B	Detailed TEMP Input	ATEC (AEC)	PM
E–180* E–60*	EDP submittal to DUSA(OR) Submittal to DUSA(OR): EDP DTP Pre-Shot prediction Report BDAR Support Plan, if required**	ATEC (AEC) ATEC (AEC) Tester ARL/SLAD or SMDC BDAR Exec Agent	N/A N/A
E	Live Fire Test	Tester	PM
E+60	Final TR	Tester	N/A
E+110	SER for FRP Decision	ATEC (AEC)	N/A
E+120	Final TR and SER to OSD	DUSA(OR)	N/A
E+180	Model Comparison Report	SLAD	N/A

Notes:
* These scheduling guidelines pertain to the FUSL LFT&E Phase. Timelines may vary for other LFT&E Phases.
** For BDAR Support Plan and Report requirements, see system LFT&E Strategy.

J–10. Elements

System developmental tests and evaluations typically address the following factors: firepower (lethality is an element); survivability (vulnerability is an element); performance; safety; reliability, availability, maintainability, and durability; manpower and personnel integration; integrated logistics support; and software. The LFT&E program addresses elements of firepower and survivability, which are compared/contrasted in table J–3.

Table J–3
Elements of firepower and survivability

Firepower	Survivability
Ability to acquire targets	Avoid or reduce acquisition
Ability to hit an acquired target	Avoid or reduce being hit given an acquisition
Ability to kill a target given a hit (lethality)*	Avoid or reduce being killed given a hit (vulnerability)*
Ability to perforate or breach target*	Protect against lethal mechanisms*
Ability to do significant damage to the target*	Limit damage to crew and hardware*
Rate of aimed fire	Design for expedient repair of combat damage*

Notes:
* Focus of LFT&E.

J–11. Sub-Elements

Both lethality and vulnerability LFT&E address system performance given a munition effect. At the sub-element level, lethality LFT&E addresses both the ability to perforate or breach the target and to do significant damage to the target. Vulnerability LFT&E addresses both being protected against lethal mechanisms and minimizing damage to the crew and hardware given an impact or breach by a lethal mechanism. In addition, vulnerability LFT&E addresses recoverability from combat damage (another element of survivability).

J–12. Differences between vulnerability and lethality

There are several subtle differences in vulnerability versus lethality LFT&E. Vulnerability LFT&E must address crew, hardware (excluding crew), and system (crew and hardware) vulnerability for threats and impact conditions that the system may not be designed to protect against and for threats and impact conditions that the system is not designed to protect against but could encounter on the battlefield. In lethality LFT&E, the FUSL LFT may focus on demonstrating lethality against the selected threat system(s) for areas that have the greatest protection and/or where differences

between competing munitions are expected (not only areas of greatest protection), relying more heavily on modeling/analysis to evaluate lethality against other target areas or other targets. For example, a new munition may not be able to breach the area of greatest protection on the threat; however, for areas that it can breach, the damaging effects (for example, probability of kill given a hit (Pk/h)) may be significantly greater than the munition being replaced.

J–13. Developing the LFT&E strategy

The LFT&E strategy is the most important element of the LFT&E process. It should be prepared and approved as early as possible in the acquisition cycle. The system evaluator has the lead for preparing and obtaining approval for the strategy in coordination with T&E WIPT. The DUSA(OR) approves the strategy for the Army before it is sent (via the TEMP) to the DOT&E for OSD approval. If consensus on the scope of the LFT&E cannot be reached, or if program constraints limit compliance with required reporting dates, these issues will be raised to the DUSA(OR) for resolution. The strategy is the foundation of the LFT&E section of the TEMP and all subsequent planning documents (the SEP, EDP, the Pre-Shot Prediction Report, and the DTP). The strategy should be detailed enough to adequately project resource requirements, schedules for major T&E efforts, and trigger long lead time planning, procurement of threats/surrogates, and modeling.

J–14. Background information necessary to develop the strategy

The first step in preparing a strategy is to do the necessary research to—

a. Understand the technical and operational characteristics of the concepts, technology, and requirements for the system being developed and how they differ from the system being replaced (where appropriate).

b. Develop a rationale for which threats are to be considered in the LFT&E. The rationale should be based upon a review of the STAR, the densities of the various classes of threat weapons and countermeasures in organizations likely to be encountered, and the frequency that various threats kill or are killed by the system from force effectiveness analyses supporting program decisions or planning studies. An accepted rationale from an approved vulnerability LFT&E plan was to break threats into major and minor threats. A major threat was either one that killed or reduced the effectiveness of a large percentage of the systems in the force effectiveness evaluation or had a high density in the force; all others were considered minor threats. Most of the shots fired in vulnerability LFT&E should be with major threats. The rationale for lethality LFT&E should be based on the threat that is driving the design (usually the most difficult target to kill given a hit).

c. Identify, for lethality LFT&E, threat target requirements and availability. The PMs provide funding and acquire targets for lethality LFT&E.

J–15. Define the critical issues

Having completed the homework on the developmental system, the next step in developing a strategy is to define the critical evaluation issues. Critical issues are developed to address overall system vulnerability and/or lethality. Testing should provide valuable inputs and a basis for refinement and calibration of vulnerability and lethality models. Critical issues vary for vulnerability and lethality and generally should address the following:

a. Vulnerability LFT&E.

(1) Crew, hardware, and system vulnerability.

(2) Known vulnerabilities and vulnerability reduction techniques (for example, increased ballistic protection, less sensitive munitions, and redundant components).

(3) Potential vulnerability reduction techniques.

(4) Processes, provisioning, repair times, and training required for BDAR.

b. Lethality LFT&E. Testing should provide valuable inputs and a basis for refinement and calibration of lethality models and databases. It should also demonstrate the following:

(1) Ability to perforate or breach the protection of the threat system.

(2) Ability to significantly degrade the combat/mission functions of threat systems given a breach.

(3) Potential lethality improvements.

J–16. Finalization of the evaluation process

During the examination of the vulnerability/lethality of the system being developed and the defining of the critical issues, the process by which the LFT&E results will be evaluated is formulated. The next step after the strategy development is finalizing the evaluation process and articulating the details of this process in the SEP and LFT&E EDP. (See para 6–28*d*.) The evaluation must crosswalk all vulnerability/lethality testing and complementary modeling and assessment with LFT&E issues. Some aspects of the evaluation process that must be examined in the development of the LFT&E strategy are—

a. Consideration of the use of M&S to address evaluation issues pertaining to system vulnerability or lethality, crew casualties, and logistics supportability.

b. Building block level vulnerability tests are planned to assess the ability of the protective system of the item under test (for example, armor and optics) to withstand impacts by threat missiles and projectiles, and to examine the ability

of critical components (for example, ammunition compartments) to withstand damage from a threat warhead or projectile that breaches the protective system. During the System Development and Demonstration Phase, the LFTs will focus on component/subsystem level to address vulnerability issues and upgrade and develop the system vulnerability model. The FUSL vulnerability LFT conducted against a full-up (combat-loaded) production or production representative system is generally the last in the series of LFTs conducted.

c. Lethality LFTs must be planned to assess the ability of the system to damage critical components and the crew. During the development and demonstration, the tests will usually focus on the warhead or penetrator's ability to breach the threat target's protective system. During PQT, impact conditions will be firmly established for the missile or projectile and the ability of the warhead or penetrator to breach the threat target's protective system will be refined. The FUSL lethality LFT is the last LFT phase and is conducted against a full-up (combat loaded) threat target. However, it is recognized that the extent of target functionality and application of combat load may be impacted by availability of assets and specific T&E requirements. However, it is unlikely that the desired threat target will be available. (The Army develops munitions/missiles to "defeat" projected threats that in most cases have not been fielded.) Therefore, FUSL lethality LFTs must use the best available threat targets. The scarcity of lethality LFT targets and their cost may dictate that these targets not be fully combat-loaded with live munitions to preclude a catastrophic loss.

d. Vulnerability models are also used to estimate the spare parts and time required to repair combat damaged components. FUSL vulnerability LFTs provide valuable inputs for refining these estimates. In addition, rapidly returning damaged systems to battle requires being able to accurately assess the damage and apply field expedient repairs. Again, FUSL vulnerability LFTs provide both valuable training and opportunities for TRADOC to refine and develop field expedient repair methods and to identify tools and materials required to execute these repairs.

J–17. Identification of the threat target and munition requirements

An integral part of LFT&E strategy development is the identification of the threat target (lethality LFT) and munition (vulnerability LFT) requirements. These requirements need to be identified early on in the acquisition cycle to allow for possible long lead times for procurement. It is very likely that some of the required threat munitions will not be available for LFT. It is also likely that intelligence data on some munitions may be limited. Therefore, LFTs may be conducted using threat munitions based upon postulated technology options derived from intelligence assessments. This will require surrogates in lieu of "real" threats. The rationale for threat surrogate selection, and the HQDA (DCS, G–2) approval of surrogate threat munitions, must be detailed in the EDP.

J–18. Rationale for selecting surrogate threat projectiles

The rationale for selecting surrogate threat projectiles for vulnerability LFTs is to match physical and performance characteristics of the projected threat. For kinetic energy projectiles, penetration into rolled homogeneous armor (RHA); muzzle velocity and impact velocity; and penetrator material, length, and diameter are typical key parameters. For shaped charge warheads, penetration into RHA; impact velocity; and warhead diameter, explosive type, and material are typical parameters. Availability and cost of surrogate projectiles may also drive the selection. Typically, U.S. projectiles and warheads will be selected as surrogates. The projectiles and warheads selected as threat surrogates must be submitted, along with the supporting rationale, by ATEC (AEC) to the HQDA (DCS, G–2) for approval.

J–19. Shot selection process (FUSL LFT phase)

In order to provide the appropriate information required to address critical LFT&E issues, the attack conditions and the munition/target impact location (that is, shotline) must be identified for each shot. The shotline selection methodology that will be used is described in the LFT&E Strategy, whereas the specific shotlines selected and the rationale for their selection must be included in the EDP. There are two types of shots: engineering and random. Engineering shots provide information and data to address specific vulnerability or lethality issues for a specific threat. Random shots are selected from the combat distribution of impact conditions (direction, location, and range) for the threats of interest. The minimum number of engineering shots should be selected first to address the vulnerability and/or lethality critical issues. Next, the number of random shots required for each threat weapon should be selected. Random shots should be reviewed to determine if any engineering shots are duplicated or if a critical issue is satisfied by a random shot. Those engineering shots duplicated by a random shot should be eliminated.

J–20. Shot selection constraints and guidance

Questions that need to be answered in order to select the number and types of LFT&E shots are as follows:

— What are the characteristics of the system being developed?
— What is the current state of knowledge about system vulnerability or lethality?
— What are the critical issues?
— What are the threats?
— What are the physical and performance characteristics of the threats?
— If threat munitions/targets are not available, then what is the rationale for threat munition/target surrogates?
— What are the program and test constraints?

— Has any high level guidance been provided?

The first five questions have been discussed previously. The last three questions are discussed below to provide an outline of the parameters to be considered in selecting LFT&E shots.

a. Ideally, system program schedules and funding should be developed based upon detailed LFT&E planning; however, early in the acquisition cycle, the level of planning is usually unrefined and decisions are made that lock in schedules and funding levels. The LFT&E program should be planned independent of constraints and then efforts must be made in developing and approving the strategy to obtain relief from schedule and resource constraints. The most likely outcome of this process is compromise and trying to work out strategies that meet the spirit and intent of the law within existing or modified constraints.

b. Test facilities may constrain LFTs. There may be a need for new facilities or instrumentation. Time and money may not be sufficient to develop new facilities. In addition, there may be competing demands for LFT facilities for concurrent system developments.

c. High-level guidance is frequently provided on the number or percentage of random shots, threats to be included, conditions to be fired, test design and statistical tests to be used in the evaluation (for example, pair-wise comparison using the Sign Test), vulnerability or lethality issues to be assessed, and test methods. This guidance must be taken into account explicitly in developing the strategy. If the guidance cannot be accommodated, then the rationale for not addressing it must be presented.

d. The other major constraints are the availability of threat projectiles for vulnerability tests and threat targets for lethality tests. For developmental systems, it is almost a certainty that threat projectiles and threat targets will not be available or, if they are, that they will be available in very limited quantities. Developing a rationale for selected threats or surrogates that is practical (in terms of availability and cost) is important, especially for lethality LFT&E.

J–21. Parameter selection and specification

a. For each munition/target combination, the following parameters must be selected and specified: range, angle of attack, and point of impact. For engineering shots, the procedure for selecting these parameters is straightforward; that is, select the threat and the required parameters to address a specific vulnerability/lethality issue. For random shots, the procedure is based on random selections from "battlefield" distributions of the appropriate parameters. The Board on Army Science and Technology (BAST) developed a methodology for selecting random shots for the Bradley Live Fire Vulnerability Test. The BAST methodology was revised for the Abrams Vulnerability LFT to better distribute the random shots over the entire vehicle when the sample size was small. The revised random shot methodology was reviewed and approved by members of the BAST. This methodology should be considered for future LFT&E programs. The random sampling parameters for direct fire threats versus an armored target are as follows:

(1) Posture (attack or defense).

(2) Range (based upon attack or defense posture).

(3) Angle of attack (stratified into equal probability intervals to ensure sampling over all possible attack angles with small sample sizes).

(4) Target side (left or right).

(5) Hull or turret.

(6) Horizontal dispersion.

(7) Direction of horizontal dispersion (left or right).

(8) Vertical dispersion.

(9) Direction of vertical dispersion (up or down).

b. The sampling parameters for random shot selection must be modified as a function of weapon class (direct fire weapons, indirect fire and top attack weapons, mines, and so forth.). For example, none of the preceding parameters apply for pressure-activated mines. For pressure-activated mines, the sampling parameters would include right or left track and the location under the track.

J–22. Exclusion rules

Exclusion rules may also be established for rejecting random shotline draws. Typically, these exclusion rules for armored targets reject shots that—

a. Do not impact turret or hull armor.

b. Are a repeat of another random shotline.

c. Are a repeat of a previous full-up vehicle shot.

d. Are expected to result in insignificant damage.

J–23. LFT&E and the TEMP

a. The TEMP is the basic planning document for all T&E and is the document by which the Army formally coordinates and approves the LFT&E strategy for a given system and communicates that strategy to OSD. The preparation and processing of TEMPs is conducted under the auspices of the T&E WIPT. (See chap 3 for guidance

concerning TEMP procedures and formats to be followed in the TEMP preparation.) The T&E WIPT provides the forum to effect coordination and resolve problems in the LFT&E process. A separate LFT&E WIPT under the T&E WIPT is formed to prepare the LFT&E strategy and the LFT&E input to the TEMP. This smaller group (chaired by the system evaluator), combined with the classified nature of LFT&E, enables these items to be developed in a more timely and efficient manner. Additionally, the LFT&E WIPT may assist in any required briefings of the LFT&E strategy to HQDA and OSD.

b. The TEMP (Part IV, Operational Test and Evaluation, paragraph d, Live Fire Test and Evaluation) will contain the LFT&E strategy for the program throughout its materiel acquisition process. The TEMP summarizes what, why, who, where, when, and how the LFT&E issues will be tested and evaluated. All LFT&E that impacts on program decisions will be outlined in the TEMP. Specific items to be addressed in the TEMP are discussed in chapter 3 of this pamphlet. For LFT&E, the TEMP—

(1) Shows the relationship of the LFT&E issues to the required technical and operational characteristics.

(2) Describes the critical vulnerability/lethality issues and evaluation criteria.

(3) Outlines the planned LFT&E; discusses the amount and type of LFT&E that will be performed to support each program decision point.

(4) Describes the shot selection process.

(5) Includes a LFT&E planning matrix covering the tests in the strategy, their schedules, the issues they will address, and which planning documents will be proposed for submission to DOT&E for approval or for review and comment.

(6) Indicates where schedule, resource, or budget constraints may impact the adequacy of planned LFT&E.

(7) Describes the modeling and simulation strategy and VV&A.

(8) Identifies LFT&E resource requirements (including test articles instrumentation that must be acquired).

J–24. Strategy briefing to the DUSA(OR)

Since the LFT&E strategy is part of the TEMP, the review and approval process established for the TEMP (see chap 3) necessarily applies to the LFT&E strategy. ATEC(AEC), in coordination with the T&E WIPT, develops the LFT&E strategy and incorporates it into the TEMP. On completion of initial coordination, but before formal TEMP submission to HQDA, it is advisable to brief the LFT&E strategy to the DUSA(OR) to solicit initial guidance/agreement in principle on the proposal. Any acquisition category program with an LFT&E requirement is necessarily on the OSD oversight list (even if just for LFT&E purposes), and thus such TEMPs must be submitted to HQDA for approval before submission to OSD (see chap 3).

J–25. LFT&E waiver

The LFT&E legislation contains a provision allowing the Secretary of Defense to waive the requirement for full-up LFT&E if the Secretary of Defense certifies to Congress that such LFT&E would be unreasonably expensive and impractical. In time of war or mobilization, the President may suspend the LFT&E requirement.

a. A request for waiver must be submitted and approved before the Milestone B decision. The review and approval process (per HQDA memorandum) for waivers is as follows:

(1) The request for waiver is prepared by the PM and must include the strategy that will be followed in assessing overall system vulnerability/lethality in lieu of full-up testing and an assessment of possible alternatives to realistic system testing.

(2) Request for waiver is submitted by the PM to the T&E WIPT for coordination and approval.

(3) For ACAT ID systems:

(a) Upon T&E WIPT approval, the PEO/PM submits the request for waiver through the DUSA(OR) for review and approval by the AAE.

(b) Upon approval by the AAE, the DUSA(OR) submits the request for waiver through the DOT&E for approval and certification to Congress by the Under Secretary of Defense (Acquisition and Technology).

(4) For less than ACAT ID systems, the PEO/PM submits the request for waiver through the DUSA(OR) for approval and certification by the AAE. Certifications and reports outlining the alternative LFT&E strategies will be submitted to Congress through the DOT&E and the Under Secretary of Defense (Acquisition and Technology).

b. The waiver process should normally be considered a last resort in addressing the full-up LFT&E requirement. The development and articulation of a well-planned strategy that takes advantage of extensive component/sub-system/system testing and a limited but reasonable full-up, sub-system/system LFT&E phase can satisfy the LFT&E requirement.

J–26. System Evaluation Plan (SEP)

In addition to the evaluation strategy, which defines the evaluation issues, the SEP includes the LFT&E issues and provides the crosswalk between the evaluation issues and the data requirements. Additionally, the data sampling plan and analysis techniques are specified to ensure the logic of the evaluation is understandable. The SEP will identify MOPs and MOEs associated with the issues developed in the strategy. The SEP will include a section describing the

types of threats or targets that the system is expected to encounter during the operational life of the system and the key characteristics of the threats/targets that affect system vulnerability/lethality. A reference to the specific threat definition document/authority will be presented with further discussion of the rationale/criteria used to select the specific threats/targets or surrogates and the basis used to determine the number of threats/targets to be tested in the LFT. Any T&E limitations or shortfalls and their impact on the evaluation will be identified. Furthermore, any previous data that will be used to support the evaluation will be discussed. For LFT&E programs, the approved SEP is provided to the DUSA(OR) when the EDP and DTP are submitted for approval (see chap 6). The SEP contains a DSM that identifies the test, existing data, modeling or analyses that will provide the information to address the issues identified in the LFT&E strategy. The SEP also contains the BCM that provides a crosswalk on the user requirements, with specification of the MOP/MOE used to evaluate requirements.

J–27. Event Design Plan (EDP)

Subsequent to the development of the SEP, EDPs are developed to detail test conditions and data requirements for use in the development of the DTPs. The EDP also describes statistical analyses, criteria, models, system comparisons, and how they support the evaluation. The EDPs provide the tester or analyst with the details on what data are required from a particular test or analysis event. The EDP will detail the decision process for foreseeable changes in the test design. If an unexpected change in the test design is required, the change to the EDP will be fully coordinated and approved by the DUSA(OR) and DOT&E. For FUSL LFT&E, the EDP is submitted to DUSA(OR) for approval 180 days prior to test initiation and it is subsequently forwarded to DOT&E for approval.

J–28. Pre-Shot Prediction Report

The Pre-Shot Prediction Report provides the vulnerability/lethality analysts' best estimate of the expected outcome of each shot before actual test conduct (that is, a pre-shot prediction). It is a requirement for all LFTs and provides a snapshot of the vulnerability/lethality analysts' current understanding of the munition/target interaction.

J–29. System Evaluation Report (SER)

The SER documents the Live Fire vulnerability/lethality evaluation and contains the assessment of the critical issues and conclusions concerning the vulnerability/lethality and battlefield damage assessment and repair (vulnerability LF programs only) of the system. The SER addresses the test objectives, issues, and criteria as defined in the SEP, EDPs, and BDAR Support Plan. It discusses the crosswalk between results and the evaluation and specifies any limitations relative to the analysis. The SER objectively addresses all aspects of the system vulnerability/lethality, both negative and positive. The evaluation will be balanced by the discussion of vulnerability/lethality based on the likelihood of occurrence on the battlefield. Not all vulnerabilities identified in a vulnerability LFT&E can be fixed. Constraints on system funding, system weight, and other aspects necessitate the ranking of the identified vulnerabilities from the perspectives of likelihood of occurrence on the battlefield and the degree of system degradation given an occurrence. The final SER provides this information to the user and to the PM for resolution. The SER is submitted to the DUSA(OR) for review and together with the Final TR is forwarded to DOT&E within 120 days after test completion. The SER and all LFT&E reports (to include the OSD assessment report to Congress) must be rendered prior to the full-rate production decision.

J–30. Model Comparison Report

The Model Comparison Report includes an in-depth comparison of the pre-shot predictions of crew and system damage and the observed test outcomes. This process requires a detailed examination of component damage states, failure modes, damage mechanisms, and so forth, to ensure a full understanding of model predictive capability.

J–31. Modeling support

Vulnerability/Lethality model outputs, typically generated by, or under the auspices of SLAD for Army programs, are used by AEC along with LF test results to address critical evaluation issues pertaining to system vulnerability or lethality, crew casualties, and logistic supportability. For MDA, the modeling agency is the SMDC. For JLF programs, and Army LFT of multi-Service equipment or munitions, vulnerability/lethality modeling may be conducted or supported by the Navy or Air Force. It is difficult to separate vulnerability and/or lethality evaluations directly supporting FUSL LFT from those required for the entire acquisition process. In a broader context, model-generated vulnerability and lethality estimates are critical inputs to system effectiveness studies, such as AoAs, designed to determine force exchange ratios, optimum tactical deployment schemes, wartime maintenance and medical requirements, and other measures of system cost and benefit. Thus, there is clearly a critical link between vulnerability/lethality modeling and system level evaluations. The following discussion attempts to provide a better understanding of the Army's vulnerability/lethality models and their role in LFT&E.

a. Much of the early controversy surrounding LFT&E focused on the adequacy of Army vulnerability/lethality models and their appropriate role in the overall LFT&E process. Too often people interpreted the debate over these issues in such a manner that modeling and testing were viewed as an either-or proposition. The fact is both are needed and are essential to a comprehensive and effective LFT&E program. They are complementary efforts and the LFT&E

strategy and planning must be based on this view. This guidance attempts to provide a better understanding of the Army's vulnerability/lethality models and their role in LFT&E. Live Fire testing, even when supplemented with developmental testing, cannot produce enough data to assess the vulnerability or lethality of a system for all combinations of threat, impact, and engagement conditions. Thus, modeling must be used to extend test results to account for conditions impractical or impossible to test. The reader is reminded that modeling here is defined in the broad sense given in the glossary.

b. In general, more than one model or sub-model must be used to characterize such phenomena as target geometry, munition performance, armor performance, Behind Armor Debris (BAD), personnel injuries, component and subsystem failure modes, aircraft airspeed and altitude dependence, and component kill probabilities. Usually, these models are implemented and applied with personal and mainframe computer codes that, depending on their complexity and sophistication, have modules to implement these models or use as input the products of auxiliary codes. It is important to recognize that the choice of models cannot be specified arbitrarily. Rather, the appropriate model or assessment technique must be chosen on the basis of how much is known about the threat munition or target, input data that are available, and perhaps most importantly, the vulnerability or lethality issues that the LFT&E program is designed to address. While the most detailed and sophisticated models consistent with these criteria should always be used, it is not unusual for one suite of models to be most appropriate for FUSL pre-shot predictions while another suite of models is best for some other aspect of the LFT&E effort. This flexibility in model selection is especially necessary for lethality LFT&E because the level of knowledge of the threat target is often extremely limited.

c. For any given LFT, whether vulnerability or lethality, the suite of analysis models must be selected by the vulnerability/lethality analyst in coordination with the system evaluator. However, once the modeling strategy is determined, it is important to create an audit trail. The underlying rationale for the model or its modification, model limitations, assessment procedures, and required input data should be documented. The models to be used must, of course, be specified in the SEP and appropriate EDPs. However, depending on the level of development of the LFT&E strategy, they may, or may not, be identified in the earliest versions of the TEMP.

d. In the context of LFT&E, vulnerability/lethality modeling has four basic roles in addition to the evaluation support mentioned above. The additional roles include support test designs, guide and evaluate vulnerability reduction or lethality, and methodology diagnosis.

(1) *Test design support.* To most efficiently utilize resources allocated for the FUSL Live Fire Test, modeling is used as follows:

(a) To determine which engineering shots make the most sense in terms of what is known about the vulnerability or lethality of the system being tested, the expected performance of the threat munitions or target, and the specific evaluation issues for the system being tested.

(b) To develop and apply exclusion rules for randomly selected shots and, once those shots have been selected, to determine from pre-shot predictions that, if any, should be conceded to avoid unnecessary loss of test assets.

(c) To "filter" random and/or engineering shotlines to ensure a specified level of damage will be considered (for example, using loss of function (LOF) matrices to identify weapon/target impact locations that satisfy a pre-selected criteria that only "shotlines with a LOF greater than or less than a certain value will be considered" or to identify weapon or target impact locations that satisfy pre-selected damage criteria).

(d) To assist in shot prioritization from least to most damaging. This will ensure that most of the testing will be completed before the high-risk shots are fired. This works well for both vulnerability and lethality tests since target repair is a major driver in the turnaround time between LFT shots.

(2) *Vulnerability reduction/lethality enhancement.* Modeling also supports vulnerability reduction and lethality enhancement efforts by allowing the analyst to evaluate the potential payoff of design changes intended to reduce casualties/system vulnerability or increase munition lethality.

(3) *Methodology diagnosis.* One objective of LFT is to determine the extent to which the vulnerability and lethality models account for all pertinent munition damage mechanisms and target failure modes. In this context, modeling, via comparing pre-shot predictions with test results, can provide insights into the fidelity of the models themselves. Seldom will enough data be generated from a single LFT program to allow a complete verification of model performance. But, insights can be gained to suggest whether significant munition/target interactions are being neglected by the models and to identify areas of model performance that need to be more thoroughly examined in on-going model improvement programs. Note that pre-shot predictions have been mandatory for FUSL LFT programs or the highest fidelity tests conducted as part of a LFT&E strategy. Pre-shot predictions are not required for efforts that are experimental in nature and are conducted to develop model inputs and algorithms. Pre-shot predictions for tests that are neither FUSL nor experimental, may or may not be required. The need for modeling pre-shot predictions should be determined in these cases by the need to validate modeling prior to FUSL or to substantiate that the model adequately predicts the target-threat interaction.

(4) *Pre-shot predictions.* Pre-shot predictions can be as simple as using a series of charts to determine if missile fragments are likely to sever a drive shaft in the FUSL LFT, or in component or sub-system level tests. At the other extreme, modeling may involve the use of several large-scale computer codes to generate distributions of damaged

components or other metrics, which take into account all known munition/target interaction phenomena and, in addition, address the stochastic nature of these interactions.

J–32. Modeling requirements and classes

Early in the system acquisition cycle there is little or no test data, and evaluations are made based upon model estimates and/or analyses. Databases to support the models should reflect the technical and performance characteristics of the system and the threat. The initial models and model inputs will probably be both unrefined and uncertain. The LFT&E strategy should be designed to increase the level of refinement and to reduce the uncertainty. A carefully crafted strategy will make use of early engineering data to refine models and develop a resource efficient building block test program to acquire the necessary data.

a. Regardless of the specific models selected to support any given LFT, there are several databases that must be developed prior to LFT. The exact nature of these databases will, of course, vary depending on the models used. However, they will usually include such things as target descriptions, threat munition and armor performance, BAD characteristics, failure modes and component/sub-system criticality, kill criteria, damage assessment lists, helicopter altitude-airspeed diagrams, and the sensitivity of combustibles to fragment and penetrator impacts. Development of these supporting databases must begin 1 to 2 years in advance of the start of the FUSL LFT. A potential problem with the scheduling of tests and analyses to generate these databases is that the data must be pertinent to the planned production design of the system or munition being tested. For example, penetration characteristics for a new projectile must be for the production design as opposed to evolutionary development prototypes. Some of these databases will be developed wholly or in part to support the overall T&E process; others are needed to directly support FUSL LFT. In any event, costs and hardware requirements must be identified as early as possible in the TEMP in order to permit their inclusion in budget and contractual documents.

b. Also, engineering models may be used to establish the performance of a particular area of the system being evaluated, either vulnerability or lethality. A well-designed strategy will make use of the building-block approach to help refine and validate engineering performance models in the execution of the LFT&E strategy. This approach can be used to build confidences in the engineering models. Some examples are finite element models to determine the blast loading on aircraft structural members, shaped charge jet penetration models, hydracode finite element modeling, shock and blast codes, and many other engineering based models. Care must be used in the selection of the models to be used and the system evaluator will need to understand where the models apply and the limitations of the models (that is, where the models are not intended to provide applicable output to the assessment of the system's performance).

c. The types of models used to support pre-shot predictions for the FUSL LFTs can include engineering models, stochastic V/L models, and simple engineering judgments. Table J–4 compares these classes for output, level of detail and applications.

Table J–4
Comparison of pre-shot modeling capabilities

Model type	Output measures	Level of detail	Applications
Engineering Judgment	Expert judgments on the potential for system, sub-system, and component level damage	Judgments can be provided at the component level in terms of a "likely" or most probable outcome	Incorporation of effects from damage mechanisms not addressed by available models
Engineering	Finite Element Models (Hydracodes, Dytan, NASTRAN, Dyna 3D) Empirical Estimates of Penetration and Behind Armor Debris	Structural Components and Blast Loading Shaped Charge Warhead Penetration, BAD Predictions	Design of Structures and Failure Limits Design of Warheads
Stochastic Point Burst (for example, MUVES–S2, AJEM)	M–Kill Pdf F–Kill Pdf M/F–Kill Pdf K–Kill Pdf Component damage state Pdf	Same as above	Same as above plus estimation of errors in field sampling, propagation of uncertainties, and calibration of lower-level models.

Notes:
* **MUVES** = Modular Unix-based Vulnerability Estimation Suite; **Pdf** = Probability Density Function; **F-Kill** = Firepower Kill; **K-Kill** = Catastrophic Kill; **M-Kill** = Mobility Kill; **M/F Kill** = Mobility or Firepower Kill

d. The vulnerability and lethality estimates do not account for combat attack distributions, deployment conditions, or weapon hit probabilities. Typically, the system evaluator applies these factors to the vulnerability and lethality estimates. Resulting metrics are then used by ATEC, TRADOC, or other agencies to evaluate system survivability or firepower to determine force exchange ratios, identify maintenance requirements, or determine some other measure of system effectiveness. Evaluation strategies must be based on the type, quality, and quantity of vulnerability/lethality estimates that are reasonably expected to be generated in light of the limitations discussed above. In addition, data requirements must be identified in a timely manner to allow input databases to be developed and necessary model modifications to be made.

J–33. Required documentation

a. Pre-Shot Prediction Report. The Pre-Shot Prediction Report provides the vulnerability/lethality analysts' best estimate of the expected outcome of each shot before actual test conduct (that is, a pre-shot prediction). It is a requirement for all FUSL LFTs (or substitute test series) and provides a snapshot of the vulnerability/lethality analysts' current understanding of the munition/target interaction. These predictions can range from subjective engineering judgments of the expected damage level through computer-generated estimates of crew casualties and loss of critical system capabilities. The SLAD (or SMDC for MDA programs) is responsible for generating the pre-shot predictions for each FUSL LFT. Appropriate pre-shot prediction techniques will be determined by SLAD/SMDC on a case-by-case basis in conjunction with the system evaluator. The SLAD/SMDC will prepare the Pre-Shot Prediction Report; it must be submitted to the DUSA(OR) along with the DTP (60 days before test initiation for FUSL LFTs). The Army approved Pre-Shot Prediction Report is forwarded along with the DTP and the EDP to DOT&E for review and comment.

b. Model Comparison Report. The Model Comparison Report includes an in-depth comparison of the FUSL LFT pre-shot predictions of crew and system damage and the observed test outcomes. Thus, this report can contain damage assessment information that will be published in the Detailed Test Report as well as additional data analysis. This process requires a detailed examination of component damage states, failure modes, damage mechanisms, and so forth, to ensure a full understanding of model predictive capability. Anomalies will be identified and, if required, model updates specified. Within 6 months after completion of the test, the SLAD/SMDC will publish the Model Comparison Report.

J–34. Verification, validation, and accreditation (VV&A)

See DA Guidelines: Use of Modeling and Simulation to Support Test and Evaluation, 18 April 2000. With the use of models in system evaluations, there is a requirement to understand the limitations associated with the models used to support system evaluation. The verification, validation, and accreditation (VV&A) can be carefully built into a LFT&E strategy in order to provide a method to examine model predictions at various stages of development of the system. Only those portions of the model not previously validated need to be addressed in this stepwise comparison to the test data to ensure the models adequately represent the physics and outcomes that the model is being used to analyze. For applications of the models used in areas previously validated, further validation is not essential. Accreditation is required for models used in support of system evaluations, regardless of previous use, to ensure the models are being used in appropriate fashion. The agency using the model accredits the model for use in the system evaluation with the support of the agency that developed the model.